

A New Soft-Switched Resonant DC-DC Converter

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Abstract- This paper presents a new soft-switched resonant dc-dc converter using a passive snubber circuit. The proposed converter uses a new zero voltage and zero current switching (ZVZCS) strategies to get ZVZCS function. Besides operating at constant frequency, all semiconductor devices operate at soft-switching without additional voltage and current stresses. In order to validate the proposed converter, computer simulations and experimental results were conducted. The paper indicates the effective converter operation region of the soft-switching action and its efficiency improvement results on the basis of experimental evaluations using laboratory prototype.

Index Terms- ZVZCS, resonant, converter, semiconductor, current switching, snubber

I. INTRODUCTION

There has been an increasing interest in the soft-switching power conversion technologies in order to overcome the limitations of the hard-switching technologies [1]-[7]. Soft-switching (SS) converters had many advantages over hard-switching (HS) converters. For example, SS converters lower switching losses, reduce voltage/current stress, reduce EMI, and allow a greater high switching frequency in high power applications [1]. Despite the advantages of SS converters, its applications have been so far limited due to complexity in the design of SS circuits, and difficult in control realization. There has been a growing demand for a simple design that provides reliable control in a wide-range of operational condition.

Several SS techniques have been developed such as the auxiliary resonant snubber inverter (RSI) [1], the auxiliary resonant commutated pole inverter (ARCP) [3], [6], the inductor coupled zero-voltage transition inverter (ZVT) [4]-[5], and the resonant dc link inverter (RDCL) [2], [7], [8]. The RSI is suitable for single or three-phase inverters with multiple branches of auxiliary circuits but needs modification of space vector modulation to ensure zero voltage switching. The ARCP requires large split capacitors to achieve a zero-voltage switching. The ZVT requires bulky coupled inductors to reset the resonant current. The RDCL needs a device voltage rating higher than that which has been used in other converters. To realize high conversion efficiency, a soft switching circuit is useful and effective technologies. And many soft-switching circuits applied to dc-dc converter have been proposed [9]-[22].

Among of these technologies, the soft-switching topologies using an auxiliary active switch method have disadvantages, such as low reliability and complexity of both the power circuit and control circuit compared to the passive soft-switching ones. The passive Snubber circuit has the simple circuit configuration and wide operation region of the soft-switching action [12], [13]. This paper presents the snubber circuit which consists of the passive components applied to the dc-dc converter. Due to its simple circuit configuration, this proposed converter is able to be controlled by a single PWM signal, establishing high reliable circuit. In order to validate the proposed converter, computer simulations and experimental results were conducted. In the simulation and experimental results, the purpose of the comparison between soft-switching and hard-switching was to investigate the following characteristics: the voltage spike, EMI noise, turn-off dv/dt , heat sink temperature, power loss and control flexibility. With the merits of simplicity and flexibility, the proposed dc-dc converter shows excellent performance and potential for various industry applications including switched reluctance motor (SRM) drives, high-frequency-high-voltage choppers, magnet drivers, and magnetic resonance imaging (MRI) system applications.

II. PROPOSED CONVERTER TOPOLOGY AND ITS OPERATIONS

A. Operation Principles

The conventional dc-dc converter circuit is shown in Fig. 1. Fig. 2 illustrates the circuit configuration of the proposed soft-switched resonant dc-dc converter which uses the passive snubber circuit, and which can be operated under the principle of low dv/dt and di/dt turnoff and turn on (ZVZCS) and simple PWM action. The main power converter circuit consists of one active switch (Q) and the auxiliary passive snubber circuit.

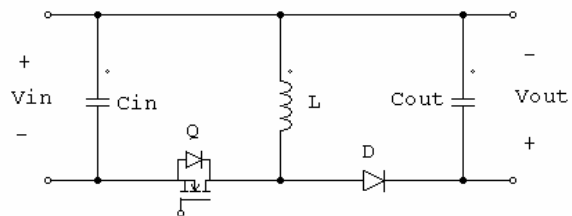


Fig 1. Conventional dc-dc converter.

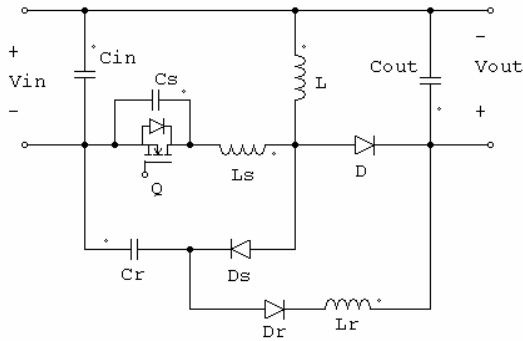
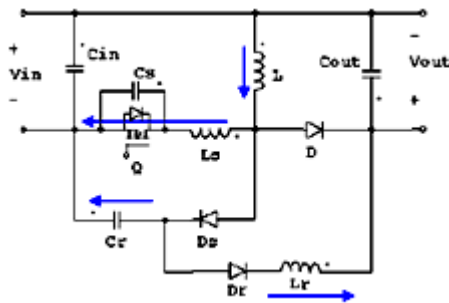
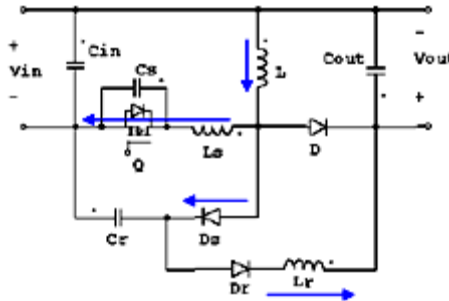


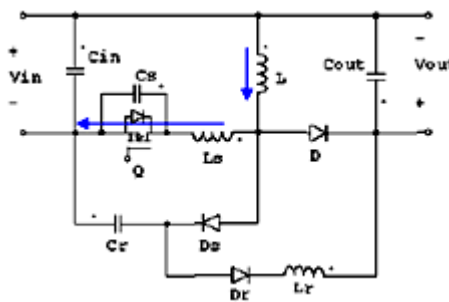
Fig 2. Proposed soft-switched resonant dc-dc converter.



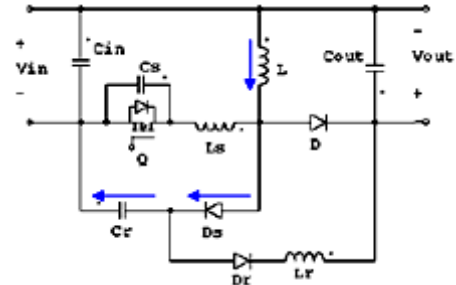
Mode 1



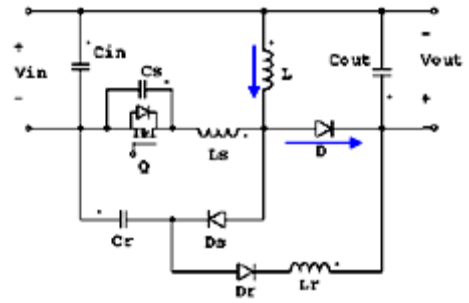
Mode 2



Mode 3



Mode 4



Mode 5

Fig 3. Operation modes.

B. Circuit Analysis

Fig. 3 indicates operation mode transition diagram of the proposed soft-switched resonant dc-dc converter. Operation of the proposed resonant dc-dc converter circuit is as follows:

Mode 1 At mode 1, the active switch Q is turned on and a voltage nV_{in} is reflected across the secondary winding of the main inductor. As a result, resonance based on L_r and C_r starts partially. The snubber capacitor voltage is discharged toward to low level.

Mode 2 When the snubber capacitor voltage is fully discharged to zero, at this time, the additional operation mode of mode 2 is started, and the C_r current decreases linearly to release the resonant inductor energy. When the C_r current becomes zero, mode 3 starts.

Mode 3 The main inductor energy is stored from the input side in this mode. When the active switch is turned off by the controller gate off signal of duty ratio (\pm), mode 4 starts

Mode 4 At this mode, the turn-off voltage applied to the active switch is suppressed by the snubber capacitor, and then the turn-off loss of the active switch becomes small. When the capacitor voltage reaches to $V_{in} + V_{out}$, mode 5 starts.

Mode 5 The energy stored in the main inductor is released to the output side in this mode.

Since deep discharge of the snubber capacitor can be obtained at the condition of small value of V_{out}/V_{in} , the large reduction of the turn-off loss of the active switch can be achieved. This means that the higher input voltage at the output constant voltage control condition grants the larger effectiveness of the efficiency improvement.

III. SIMULATION RESULTS

The proposed two quadrant soft switched converter in the PSIM software environment is shown in Fig. 4. The following circuit parameters have been used in simulations:

- 1) A MOSFET module at 400V - 10A was used;
- 2) The resonant capacitor C_r used was 120 nF- 50V polypropylene capacitor;
- 3) The resonant inductor L_r used was $47 \mu H$;
- 4) The snubber inductor L_s used was $10 \mu H$;
- 5) The snubber capacitor C_s used was 1nF;
- 6) The input and output capacitors (C_{in} and C_{out}) used were $470 \mu F$;
- 7) The diodes D and D_r used were 1N4500;
- 8) The resistance 1Ω is used as a load.

The waveforms of v_{ds} and i_{ds} of the switch Q is shown in Fig. 5. The output dc voltage (V_{out}) is shown in Fig. 6. The simulation results show that the proposed soft switched resonant dc-dc converter has the proper response.

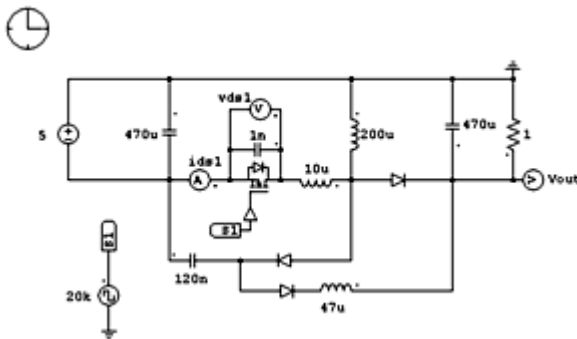


Fig 4. Proposed soft switched resonant dc-dc converter in PSIM software.

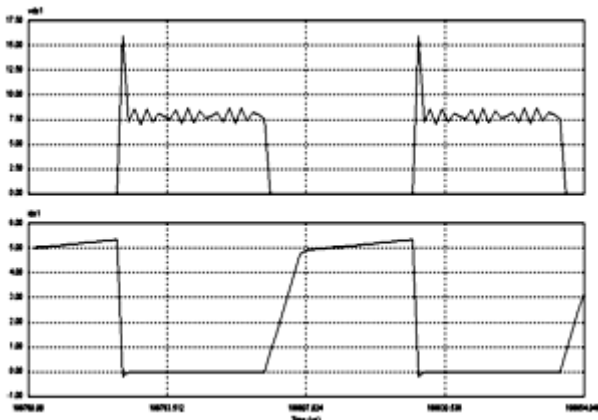


Fig 5. V_{ds} and I_{ds} waveforms of the switch.

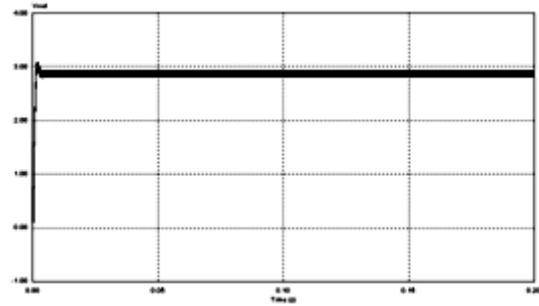


Fig 6. Output dc voltage (V_{out}).

IV. EXPERIMENTAL RESULTS

A Prototype of the proposed converter, as shown in Fig. 7 has been built in the laboratory. The newly proposed converter operates with an input voltage $V_s = 3.67V$, output voltage $V_o = 1V$, load current of 0.6A and a switching frequency of 50 kHz. The V_{DS} and V_{GS} waveforms of MOSFET switch in a time period of one switching cycle are shown in Fig. 8 and Fig. 9 respectively. The voltage across resonant capacitor 120nF is shown in Fig. 10. The clock signal in a time period of one switching cycle is shown in Fig. 11. The output DC voltage is shown in Fig. 12.

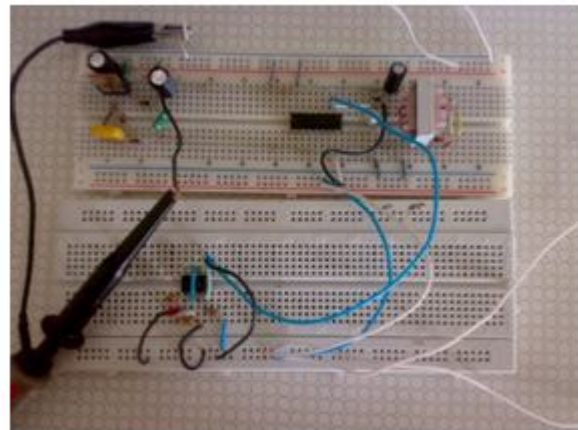


Fig 7. Prototype of the proposed converter.



Fig 8. Drain-source (V_{DS}) signal:

Volt/Div = 0.5 v, Time/Div= 10 μs , $V_{in} = 3.66$ v, $I_{in} = 0.6A$

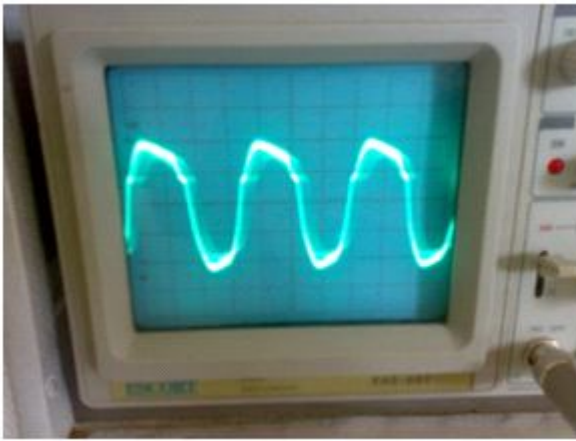


Fig 9. Gate signal:

Volt/Div = 5v, Time/Div= 10 μ S , V_{in} =3.67 v, I_{in} =0.6A

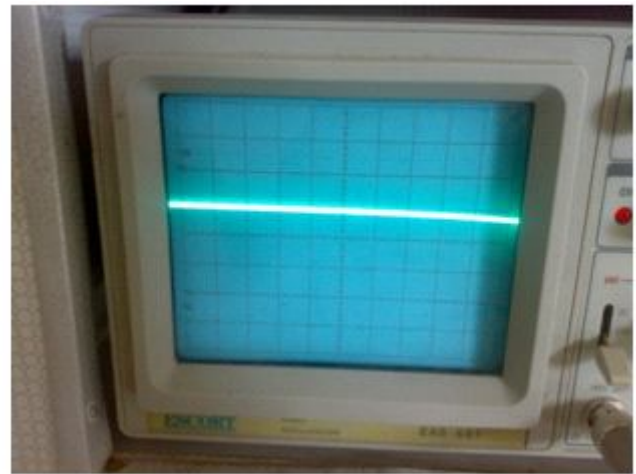


Fig 12. The output DC voltage:

Volt/Div = 1 v, Time/Div= 0.5 ms, V_{in} =3.67 v, I_{in} =0.6A



Fig 10. Voltage across resonant capacitor 120 nF:

Volt/Div = 50 mv, Time/Div= 10 μ S , V_{in} =3.62 v, I_{in} =0.6A

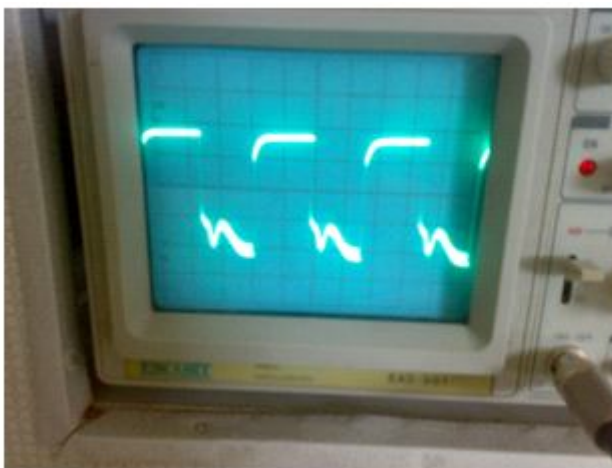


Fig 11. The clock signal:

Volt/Div = 1 v, Time/Div= 10 μ S , V_{in} =3.67 v, I_{in} =0.6A

CONCLUSION

In this section, a new soft-switching converter topology with a simple resonant snubber circuit was proposed and was verified fully for working conditions with a load. In order to verify performance of the proposed converter, circuit simulations using PSIM software and experimental results were given. With the merits of simplicity and flexibility, the proposed soft switched dc-dc converter shows excellent performance and potential for various industry applications including switched reluctance motor (SRM) drives, high-frequency-high-voltage choppers, magnet drivers, and magnetic resonance imaging (MRI) system applications. The operation principle of the proposed circuit, its design consideration and efficiency characteristic are described on the basis of theoretical and experimental point of view. It is verified that the efficiency of the proposed new soft-switching converter increases when the passive snubber circuit is implemented compared to the hard-switching operation.

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